DEVELOPMENT OF A HIGH STABILITY WATER VAPOR RADIOMETER

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ABSTRACT

Preliminary design details and laboratory test results of a microwave radiometer operating near the 22.2 GHz water vapor resonance line are presented, Radiometric stability to 10mK for periods of several hours is the design goal. Early indications are that these goals are being met in the prototype system. The use of noise diodes as receiver gain calibrators is examined, and test results showing 30 parts per million stability in the inter-comparison of noise diodes are presented, Temperature control of the radiometer is also discussed, and the design of a solid state temperature control system capable of 1 mK stability near room temperatures is presented, A new design for a Dicke switch is also presented,

1. INTRODUCTION

An Advanced Water Vapor Radiometer (AWVR) is presently being developed at JPL to support planned radio science experiments involving NASA's Deep Space Network (DSN) and the Cassini spacecraft, The AWVR will operate at frequencies from 22 to 31 GHz, and will be used to measure atmospheric water vapor along a line of sight from ground based DSN antennas to the spacecraft. The water vapor data will then be used in conjunction with other atmospheric parameters (see *paper by Keihm in this issue)* to estimate atmospheric path delay fluctuations on the DSN telemetry signal. The AWVR is to operate out doors in a desert environment along side DSN stations at NASA's Goldstone facility for a period of up to ten years. During radio science experiments the AWVR will track along with the DSN antenna to provide path delay data continuously for up to 24 hours. In this time span the instrument calibration should be stable to 10 millikelvin in brightness temperature. On time scales of days, stability to 50 millikelvins is desired. Such performance exceeds the demonstrated stability of existing water vapor radiometers. Thus, the present work has focused on underlying causes of radiometer instability. Two areas of particular concern are instrument temperature control, and of the stability of noise diodes as gain calibrators.

Various architectures for radiometers are discussed extensively in the literature [*Kraus,* 1966; *Ulaby et al., 1982*], and each is characterized by the method used to stabilize the receiver against instabilities in gain and offset, Based on experience with previous generation water vapor radiometers [*Janssen*, *J* 984; *Resch et al., 1985*], a scheme illustrated in Figure 1 was selected for the AWVR. The RF switch in Figure 1 that diverts the input from the antenna to the matched load is commonly referred to as the Dicke switch, and the noise diode and coupler together form a noise injection circuit. The Dicke switch and noise diode calibration circuits are controlled by a computer which then measures the radiometer's output voltage via the analog to digital converter (ADC) in response to the various sources. The computer combines the results in software to produce the brightness temperature estimate.

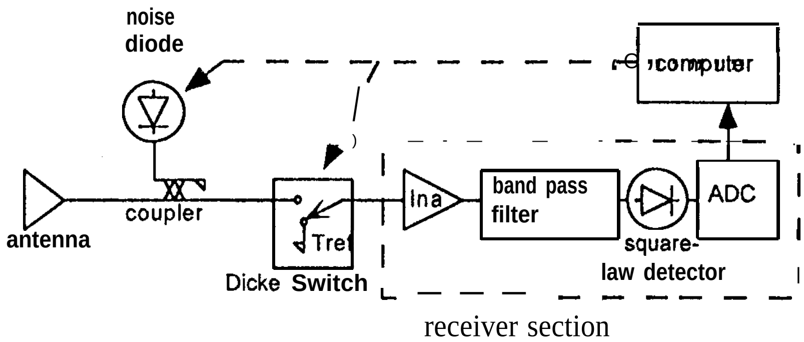


Figure 1 :**Simplified diagram** of a **Dicke** radiometer with noise injection

When the Dicke switch of Figure 1 is in the reference position the matched load presents a black body brightness temperature equal to its physical temperature at T_{ref}. This provides a single reference point which should be equivalent to putting a microwave absorber- at the reference temperature- in front of the antenna, The degree to which this equivalence holds true depends on the RF performance and on the temperature control of the components prior to and including the Dicke switch. Impedance matching is important so that the low noise amplifier (LNA) is presented with same source impedance in both positions of the Dicke switch, Insertion losses should also be held to a minimum. Where losses can not be eliminated, the temperature of components should be well known or controlled. Note that if RF losses exist between the antenna and the Dicke switch, then the above equivalence can still hold true so long as these parts are held to the same reference temperature [*Hardy, 1974*]. And since these losses typically are significant, often totaling 1 dB to 3dB, the control and the knowledge of temperature becomes a first order problem in the design of a radiometer. Temperature control will be the topic of section 2 of this paper. impedance matching issues will be discusses throughout this paper.

The noise diode of Figure 1 is used to monitor radiometer gain. The gain, for the present discussion, is the ratio of output volts of the detector circuitry to input brightness temperature, Instabilities in RF amplifiers and other components continuously cause the gain to change. When the noise diode is switched on, noise is added to the antenna signal and the radiometer's detected output is deflected by some voltage. The magnitude of the deflection provides a measure of gain, provided that the equivalent antenna brightness temperature of the noise diode is known. An initial calibration is required to establish an equivalent antenna brightness temperature for the noise diode. For the AWVR, the opportunity to calibrate the noise diode may not present itself for days at a time. So the stability of the noise diode and the stability with which the noise diode can be compared with the antenna brightness temperature is critical. Noise diode stability will be the subject of section 3.

2. TEMPERATURE CONTROL

There are numerous benefits to controlling radiometer temperature. As discussed above, maintaining radiative balance in the front end components is key, Additionally, many RF components- such as noise diodes, couplers, and bandpass filters- have temperature coefficients associated with them which can be significant. For example, typical noise diode sensitivities are about O. 1°A / K, which for the AWVR translates to 0.3K radiometric error for 1 K temperature error. Because the AWVR will operate in a desert, where temperatures will change tens of kelvin from day to night, temperature control for the AWVR is a clear necessity, As a goal, the AWVR development has proceeded with the assumption that 10mK of radiometric stability requires 10mK of stability in the instrument physical temperature.

The design of a temperature control system for the AWVR drew from experiences with prior attempts. At JPL, the J-series WVR [*Janssen, 1984*] employed a thermo-electric cooling element to maintain a constant temperature on an internal heat sink plate to which all RF components were mounted. The surrounding enclosure then provided insulation from the outside environment. In practice this arrangement was found to achieve about 1 kelvin RMS stability on most of the components from day to night. Problematic in this design was that temperature gradients of several degrees appeared across many of the critical RF components. These gradients changed from day to night due to heat losses through the insulation. A considerable contribution to these gradients also came from active (i.e. heat producing) components which were placed on the same heat sink plate. In another radiometer, the Langley Stepped Frequency Microwave Radiometer (SFMR) (*Swift*, C. *T., personal communications, 1995*) employed a design which addressed the latter problem by mounting each component on a heat sink which was sized in proportion to the component's heat output. The design intended for the components to settle to a single reference temperature, A similar system was attempted using a cooled base plate on an early breadboard test for the AWVR. But the thermal conductivity into a heat sink was found to be very difficult to predict, The slightest change in the physical connection between a component and heat sink- such as a small change in surface roughness or a change in the torque of a mounting screw- greatly influenced the conductivity. Temperature gradients within a component's enclosure were also significant, Another problem in this design was the mechanical complexity and the difficulty of adding or changing parts with different heat outputs. So this approach was abandoned, A better approach was found in which the active components were cooled on a separate plate that was thermally isolated from the critical front end components. This eventually led to the design for the AWVR depicted in cross-section in Figure 2.

The system depicted in Figure 2 has become known as the "box within a box," There are two thermo-electric coolers (TEC's) in this system, The main TEC controls the temperature of air which is circulated by fans in the main cavity around a box containing the RF electronics. A secondary TEC controls a base plate within the RF box, Both TEC's are under the control of a computer which collects temperature data from sixteen different sensors distributed throughout the radiometer. All heat producing RF components, primarily amplifiers and noise diodes, are mounted to the secondary 'cold plate.' Insulating foam is packed above and around this plate to prevent heat from rising off of the individual components and into the RF cavity. Coaxial cables connect the active components on the cold plate to the components contained within the RF cavity above. The active components are cooled by the secondary TEC such that the temperatures of the coaxial cables are very close to the reference ambient temperature as they enter the RF cavity, The RF cavity provides an isothermal environment at about 35C. To a stability of about 0.1 K all sides of the RF box can be held to the same temperature from day to night by circulating air from the main TEC. The average of the box side temperatures can be controlled to a much finer degree, however. And by adding insulation to the interior of the RF box, stability to about 1 millikelvin RMS is attainable for passive components within the RF box.

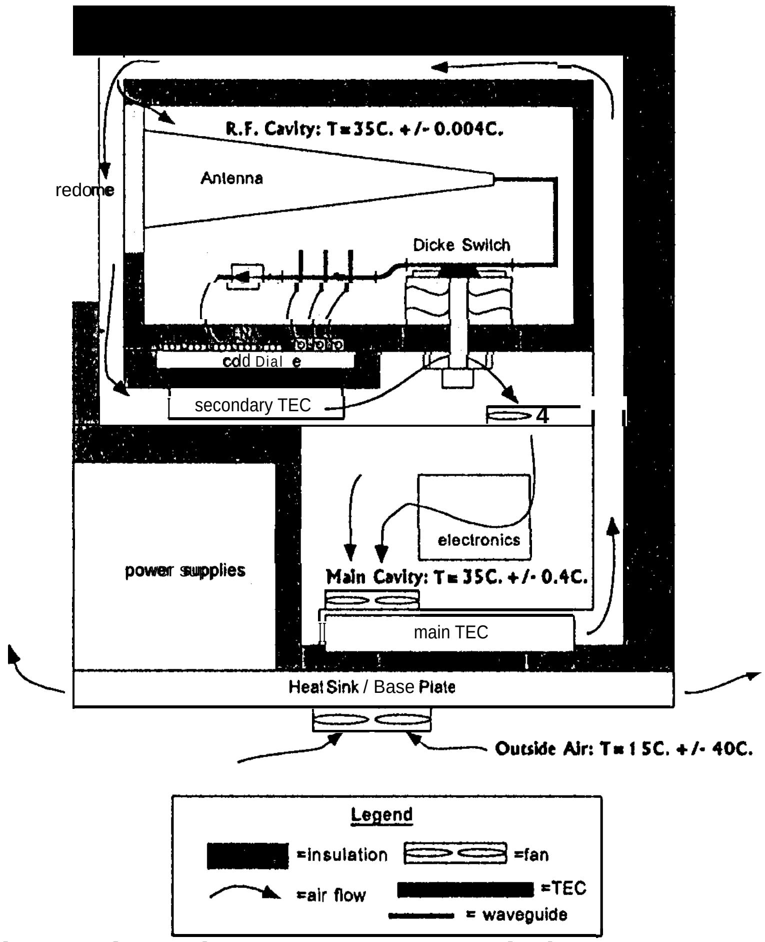


Figure 2: Planned AWVR layout showing temperature control scheme, A similar system was developed and used for the noise diode and prototype radiometer tests,

The above stability is dependent on the quality of the temperature sensing and control system. The AWVR prototype uses common epoxy encapsulated thermistors and a special low-current resistance measurement circuit, as shown in Figure 3a, This circuit uses precision operational amplifiers to acquire a resistance measurement from the thermistor with about 10 μA of current, The low current prevents self-heating of the thermistor. Measurements are made relative to a fixed reference resistor which is selected to equal the resistance of a thermistor at the target ambient temperature. The output voltage range is +/- 5 volts corresponding to a temperature error of about +/- 5K above or below the target, or reference temperature. One amplifier is used for each of sixteen thermistors, The use of solid state switches to multiplex many thermistors into a single amplifier was avoided for fear of coupled charge and leakage problems. Instead, the multiplexing function was deferred to a commercial analog 1/0 board installed in a personal computer, With 16-bit resolution in the ADC, the temperature resolution of this system is about O. 15mK. To further enhance the precision, the 5 volt reference voltage source may be switched in polarity under the control of the computer so that amplifier bias currents and voltages may be negated in computer software. A calibration of this system was performed using an alcohol bath, and regression fits were applied to each thermistor to produce a set of calibration coefficients. Absolute accuracy of the sensors is approximately 0.05K, and the stability is believed to be better than 0.5mK. The latter figure is an estimate based on comparisons of different thermistors, so common mode drift may exist which could degrade this figure.

The control circuits of the TECS are illustrated in Figure 3b. Two control voltages drive the TECS via 16 bit digital to analog (D/A) converters. The TEC's are capable of both heating and cooling. The computer software is primarily responsible for the fine tuning and balancing of the TECs. For safety, a direct analog feedback path is also included in the TEC control to prevent more than a maximum SK temperature error in the event of a software problem. A great advantage to the computer control is the ability to apply complex feedback schemes based on multiple temperature sensors. Very long integration time constants are possible which would otherwise be difficult in an analog system. Also, temperature versus time derivatives may be applied to the feedback to optimize the time response of the system. Upon initial power-up, the AWVR prototype enclosure requires approximately 2 hours to stabilize to the millikelvin level, This time constant is determined mostly by the response time of the waveguide components which are thermally well isolated within the RF cavity,

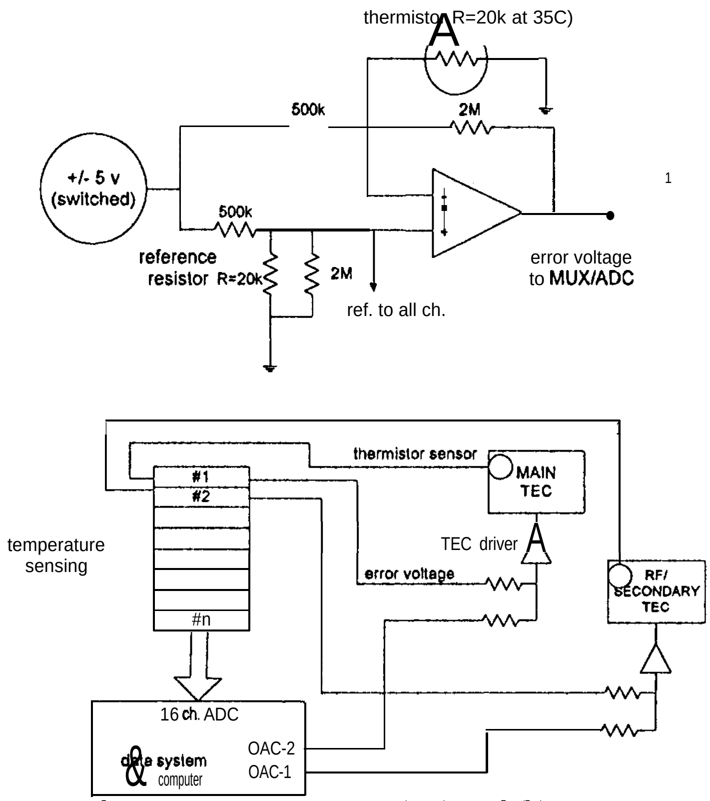


Figure 3: (a) One of sixteen thermistor sensing circuits (top), and (b) thermo-electric cooler control,

For the past two years the above temperature control system has been employed in the AWVR . development, The system was used during a series of noise diode tests discussed in the next section, and was used out doors during tests of a single frequency radiometer breadboard,

3. NOISE DIODE STABILITY

The antenna brightness temperature measured by the AWVR will be in the range of 10 to 100 Kelvin when observing the sky. Yet the internal reference of the AWVR will be almost 310 K. To resolve the antenna brightness temperature to 10mK will thus require an ability to extrapolate from the reference temperature to the antenna temperature with a precision of about (1 0mK/300K=) 30 parts per million (ppm). To do so will require stability in the radiometer gain, and this, in turn, will depend on the stability of the noise diode. Prior experience with several radiometers at JPL indicated that noise diodes could not be trusted to a level better than about 0.1 %, or about 1000 ppm on 1-day time scales. Some published data from the National Bureau of Standards [*Kanda, 1977*] also show 1400 ppm RMS stability in noise diode output power over the course of 1 day. A demonstration of improved stability was thus considered crucial to the success of the A WVR, and a series of laboratory tests were conducted,

Initial tests of noise diodes at 20.7 GHz were conducted using the RF circuit of Figure 4. Noise diode stability was evaluated by the comparison of two noise diodes. Each noise diode could be switched on and off under computer control, and the data acquired was sufficient to evaluate the stability of one noise diode as held to the standard of the other noise diode. The stability of the RF amplifiers and detection circuitry was insufficient to derive a direct measurement of either noise diode. So any common mode drift in the two noise diodes can not be measured with this test. An important assumption underlying these tests is that such common mode errors should be smooth and slow changing. Every precaution was otherwise taken to isolate the biasing circuitry of the two noise diodes to minimize common mode errors. The temperature control described in the previous section was also important in this regard as temperature fluctuations were effectively eliminated from the problem.

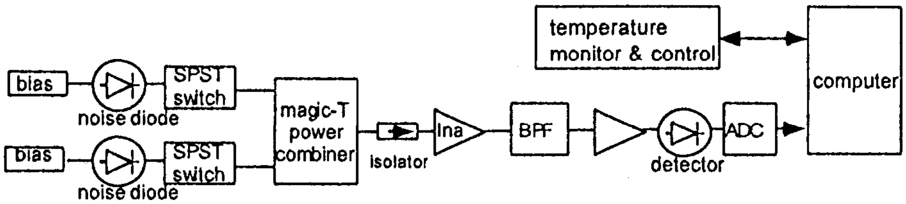


Figure 4: Early noise diode test configuration (the RF switches and magic-T were later abandoned).

Early tests of noise diode stability quickly answered a number of important design problems. One was a question of how to bias the noise diodes, Two different sets of noise diodes were procured- one in waveguide and one with coaxial connectors- and both were delivered with instructions to bias the noise diodes with 28 volts. Internally, the noise diodes used resistors to derive a proper bias current from the regulated voltage. When either of the noise diodes were tested in this mode (voltage regulated) the stability was no better than 0.2°/0 over time scales of about 10 to 100 seconds. With current regulation this figure immediately improved to 0.010/0, or 100ppm, on the same time scales. High stability current regulation was thus identified as one key to noise diode stability. This 'discovery' was not necessarily a surprise as it had been known that current regulation was preferred. Yet quantitative data was previously difficult to find, and indeed many radiometers have been built using voltage regulation.

Another issue which was soon resolved in the noise diode tests was a matter of how to switch the noise diodes on and off. Considerable power is drawn by the noise diode (100mW or more) and there had been some speculation that the noise diode should be continuously biased so that temperature cycling problems were minimized, An RF switch is thus required to control the noise diode as is shown in Figure 4, As an . alternative, a switched current source was developed and tested in place of the RF switches. Results of these tests revealed that noise diodes can be switched on and off with the bias current with no degradation in stability so long as the noise diodes are operated with a constant duty cycle at a high enough repetition rate, Thus far, all of the AWVR tests have been conducted such that the noise diodes are switched on for one measurement cycle lasting just 1.6 ms, at a repetition frequency of a fixed 104 Hz, Such a short cycle time may help reduce temperature induced problems; thus, there is no certainty yet that longer measurement cycles will result in the same stability. However, the AWVR is not constrained by either of these factors and the elimination of the RF switch was a welcome change to the design.

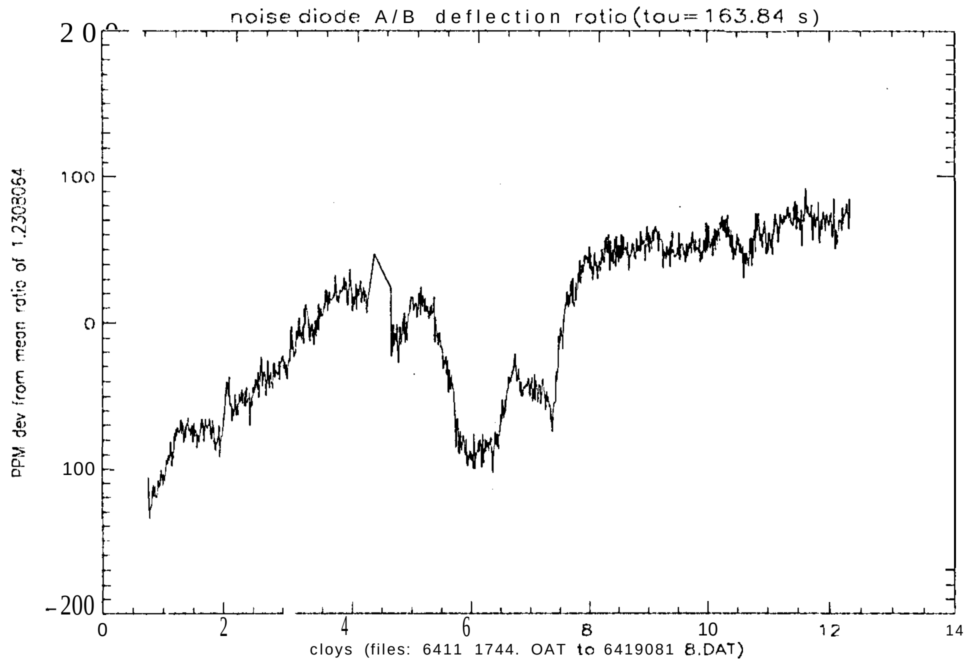
As work progressed with the noise diode tests, an apparent barrier arose where stability to no better than about 500 ppm per day could be demonstrated, Many possible error sources were examined: The noise diode current regulator design was refined and tested, and current stability to a level of just a few ppm over the course of days was demonstrated, Temperature control was examined repeatedly and the result was always that the observed temperature instabilities of 1 to 2 mK could not explain the noise diode output instability. A new set of high reliability, hermetically sealed, broad-band noise diodes was procured and tested, and still no improvements could be made. Next, a test in which a single noise diode was wired to both current sources confirmed that there were no 'back-end' problems such as ground loops. Another test was conducted in which a single noise diode was split with a magic-T, then switched with diode switches, then re-combined in the magic-T as in figure 4. This test showed the same 500 ppm instability and thus narrowed the problem down to just the magic-T and a few interconnecting components. The interconnecting coaxial cables were then rebuilt using high quality K-type connectors, and waveguide flanges were all carefully lapped to improve RF loss and standing wave characteristics. Some marginal improvements were made, but still there were no 'breakthroughs.'

Finally, while examining a long data set, it was noticed that two storms had moved through the area coincidentally with two large perturbations in the noise diode comparison. Humidity thus became suspect, and potential sensitivities to humidity included the carbon absorber of a waveguide termination and the ferrite material of an isolator, These were connected to the delta and sum arms of the magic-T, respectively, and were used to isolate the two noise diodes. The isolation between the two noise diode ports of the magic-T had been measured at -40dB which was originally thought to be sufficient. However, even at this low value, a small change in the reflection coefficient of either the matched load or isolator can change standing waves within the magic-T significantly. Furthermore, the noise diode measurements were always made with the opposing noise diodes switched off, and this resulted in a poor match. Thus, any leakage across the magic-T was reflected straight back into the magic-T and towards the receiver. Depending on the phase of the reflection, for example, this -40 dB leakage could have impacted the noise diode power level by as much as 4% (-40dB translates to a voltage standing wave ratio, or VSWR, of 1.02, or about 1.04 in power). Extreme sensitivity to the port impedances of the magic-T was thus identified as a serious flaw in the configuration of Figure 4.

A new configuration using two directional couplers to inject the noise diodes into a common waveguide path was built to replace the magic-T. Such a configuration is essentially the same as that which will be used in the working radiometer (see Figure 7). By using directional couplers, most mismatches in the system may be reduced to second order problems as compared with the magic-T. With this new configuration the relative stability of the two noise diodes finally improved to a level of better than 100 ppm over the course of a day, A log of humidity in the laboratory was also started. A sample time series plot of the noise diode comparison is given in Figure 5 along with relative humidity data for a 12 day time series. The noise diode "A/B deflection ratio" is defined by the power ratio:

$$R_{AB} = \frac{C_A - C_N}{C_B - C_N} \tag{1}$$

where CA and C_B are the counts recorded from the ADC, proportional to volts out of the detector, from noise diodes A and B, respectively, C_N is the counts recorded with both noise diodes turned off. The scale of Figure 5 has been normalized to the mean value of R_{AB} and has been offset from unity so that the stability, in part per million, may be easily read, The time series of Figure 5 spans 12 days, and data are plotted about every 200 seconds. Data are also averaged over the same interval, In this case the peak-to-peak change in the noise diode deflection ratio is about 200 ppm over a span of 12 days, with the greatest changes coinciding with changes in humidity. Thus, although the use of directional couplers improved the noise diode comparison, there was still a significant correlation with humidity, The exact areas of sensitivity were not examined, however, since the control of humidity in the AWVR will be relatively easy. Figure 6 gives an example of the noise diode deflection ratio when the humidity is controlled by purging the test fixture with dry nitrogen, In these plots we see that the noise diode is potentially stable to just 30 ppm per day, It is important to emphasize, however, that there may well be some common mode drift in both noise diodes that these plots can not show. The ultimate measure of the long term stability may not be known until the AWVR system is in full operation and can be monitored for many months using conventional calibration techniques.



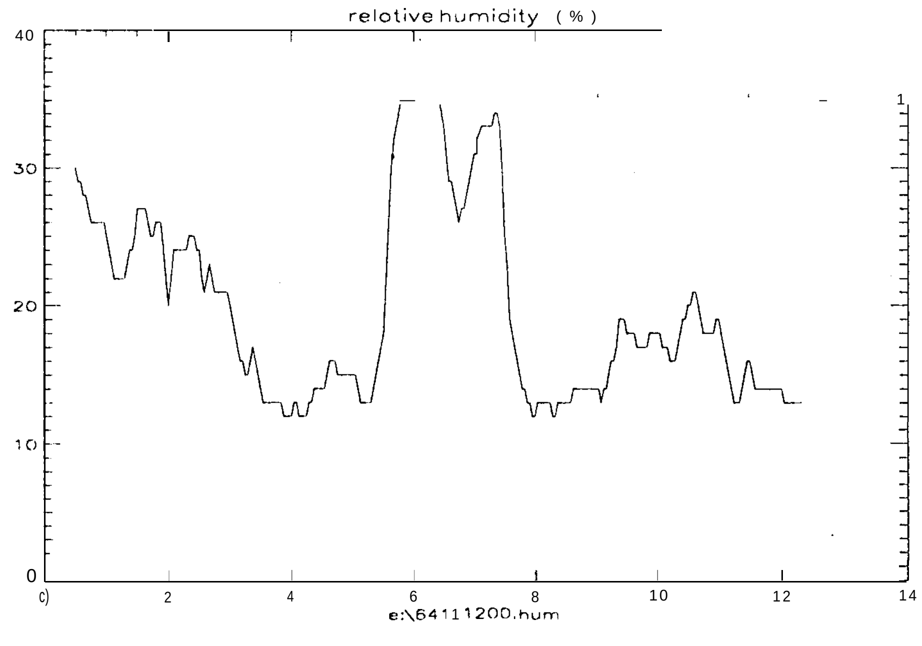


Figure 5: Noise diode deflection ratio versus time (upper plot) for a 12-day test in which humidity (lower plot) was not controlled,

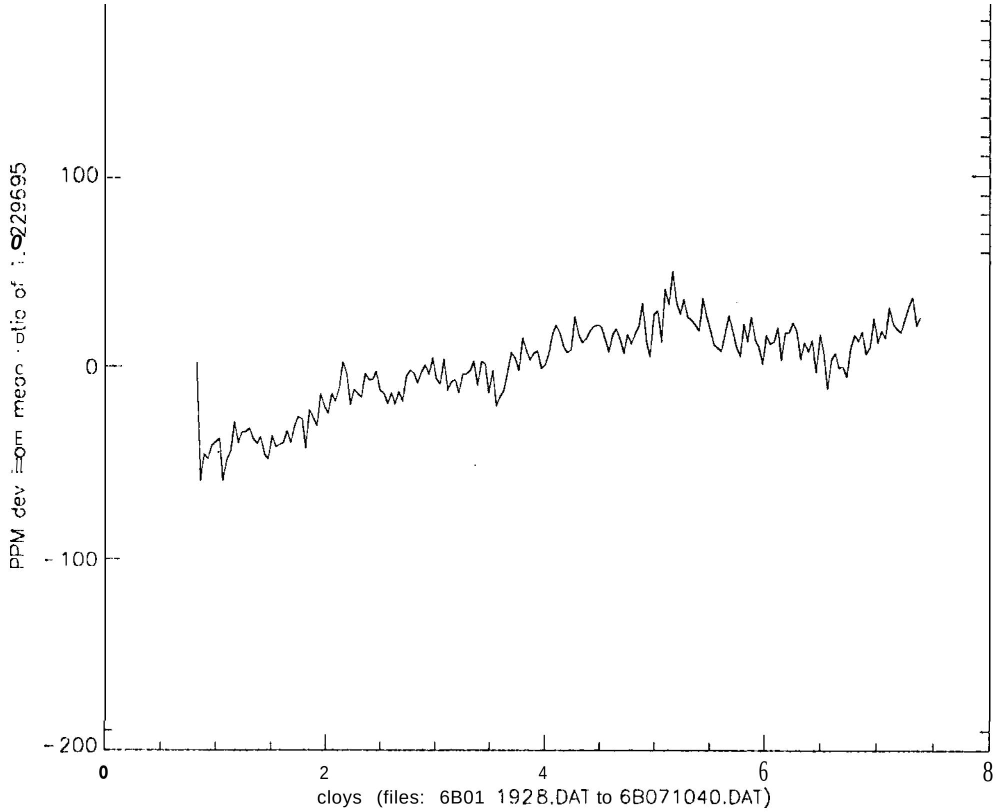


Figure 6: Noise diode deflection ratio for a test in which humidity was controlled. Data were collected from the completed prototype radiometer of Figure 7 during rooftop tests.

4. PROTOTYPE RADIOMETER DESIGN

A. Antenna and Radome

Having achieved satisfactory results with temperature control and noise diode stability, work has proceeded toward building a radiometer prototype, The prototype would use the same thermal enclosure and much of the electronics as the noise diode test fixture. The prototype would operate at a single frequency of 20.7 GHz so that it could be compared with an existing WVR. An antenna and a Dicke switch were required, along with modifications to add a radome to the enclosure. To our good fortune, a suitable antenna was made available from spare parts of the Nimbus E Microwave Spectrometer (NEMS). The antenna was a lens loaded corrugated horn built. for 22.2 GHz, so some tuning to a new frequency of 20.7 GHz was required, The antenna half-power beam width (HPBW) was approximately 15 degrees, and the beam efficiency was not known as no antenna pattern measurements were available. However, beam efficiency was not considered a problem for the prototype tests which would be conducted in a fixed zenith pointing geometry.

An antenna radome was cut from 0.5 inch thick sheets of 1 pound/ft^3 density expanded polystyrene (EPS). These were placed in apertures cut into the RF enclosure and into the outer enclosure, respectively, so that air could circulate between them (see Figure 2). Tests were conducted with a radiometer to determine radome RF losses. Thick stacks of 1 and 2 lb./ft^3 EPS sheets were placed over the radiometer antenna while viewing a clear sky. Excess brightness temperatures above the background sky temperatures were measured, and it was determined that approximately 70mK of excess noise resulted from each inch of one lb./ft^3 EPS (equal to 0.5" of 2lb. density EPS). At an approximate physical temperature of 300K such a noise temperature translates to about 0.001 dB loss per inch per pound of density. With such losses, and for an estimated 10 K temperature change from day to night, the contributed excess noise temperature should change less than 1.2mK for the 0.5 inch thickness of exterior radome material of the AWVR prototype. We should note, however, that no measurement of the radome reflectivity was made. The above tests were conducted with thick (more than 10 inch) stacks of material that may well have masked reflection effects at levels of 0.1K or less. Further tests in this area maybe needed.

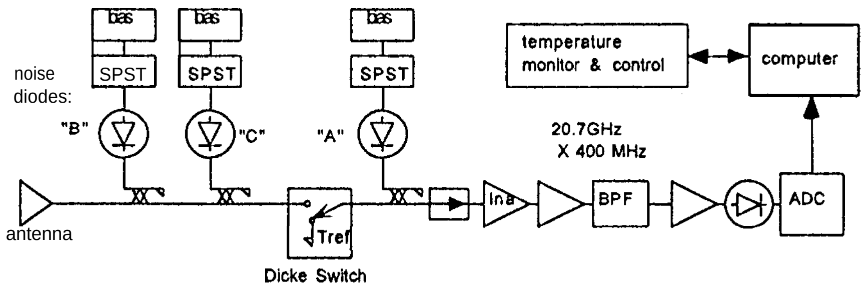


Figure 7: Prototype, single channel AWVR

B. Dicke Switch

The next modification to the test-bed system was the addition of a Dicke switch. Early design studies had identified latching ferrite circulator switches for this function, but there were a number of problems. One problem was that no ferrite switch could be found that would operate over the entire AWVR band from 22 to 32 GHz. A frequency diplexer just after the antenna would have been required, which would have complicated the front end design, Another problem with ferrite switches was that isolation and return loss performance figures fell short of goals, The performance desired of the switch was for more than 45dB isolation so that less than 10mK of the cold sky brightness temperature would leak through the switch during the reference load measurement. Two or possibly three ferrite switches would have been required to meet such an isolation requirement. Also, the return loss of available ferrite switches was not better than -20 dB, which implied that extra isolators would be needed between the switch and the LNA. Taken together, the additional losses incurred by adding these components would have contributed significantly to the system noise temperature, These problems, along with schedule and cost issues, caused the AWVR development effort to turn towards alternative switch designs. The result of this effort was a novel idea that would use a waveguide vane attenuator fitted with a high speed actuator to perform the Dicke switch function.

The RF characteristics of common vane attenuators were found to be very well suited to the AWVR Dicke switch problem. A laboratory unit was tested and found to exhibit isolation in excess of 45 dB at the maximum attenuation setting and insertion losses less than 0.3dB at the minimum setting, Return loss was also well in excess of 40 dB over the full WR-42 waveguide band from 18 to 26 GHz. The simplicity of the device was also attractive as it lent itself well to the addition of a mechanical actuator. Within a month such an actuator was completed and ready for laboratory tests, A loudspeaker voice coil and suspension was selected for the actuator. The concept is illustrated in Figure 8, which shows the cross-section of a working model that has been tested in the AWVR prototype. The vane attenuator consists of the microwave absorbing vane that is inserted through a slot cut into the broad wall of the waveguide. The voice coil actuator moves the vane through 1/4 inch of travel in and out of the WR-42 waveguide to provide the Dicke switch function, and the temperature of the vane provides the reference brightness temperature for the radiometer.

Advantages to the voice coil actuator include speed, longevity, and precision. The vane can be moved back and forth without any contacting or sliding parts so there is little to wear out. The loudspeaker 'spiders' suspend the entire moving voice coil and vane assembly with sufficient precision to keep the vane from ever contacting the 0.03 inch narrow waveguide slot. As tested, the prototype model has been operated continuously at a Dicke switch repetition rate of 5 Hz for four months- which translates to 50 million switch cycles- without any sign of wear. A continuous Dicke switching frequency of greater than 1 Hz is required in the AWVR by, in part, the fact that continuous observations to one second in time resolution are needed. RF amplifier instability also contributes to the Dicke frequency requirement: data from the noise diode tests show that at much lower frequencies the amplifier instabilities (l/f noise) exceeded thermal (Gaussian) noise so that radiometer performance would be degraded,

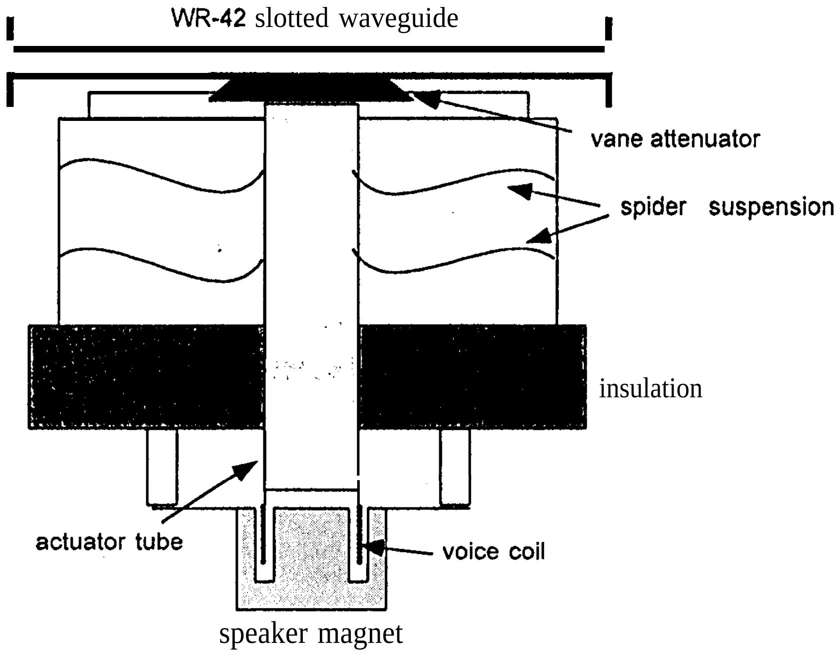


Figure 8: Cross-section of the voice coil actuated Dicke Switch (also see Figure 2)

To provide a stable reference temperature for the radiometer, the heat dissipated at the voice coil must be well insulated from the vane itself. To this end the vane is attached via an insulating and light weight structure consisting of a thin walled fiberglass tube filled with expanded polystyrene (EPS). The moving structure has a total mass of about 15 grams including the copper voice coil windings. The speaker magnet is mounted on a ventilated exterior panel outside the RF cavity of the AWVR prototype fixture in a manner similar to that shown in Figure 2. Close fitting insulation separates the voice coil and magnet from the RF cavity. As tested, the physical temperature of the vane, as well as the radiometric brightness temperature of the vane, was found to increase by just 0,03 K when the actuator was started and left to run at a continuous 5 Hz, Stability in the temperature of the vane is approximately 2mK at the same 5 Hz rate, Temperature figures were found to degrade rapidly as switch speed was increased. Other specifications are summarized in Table 1.

DICKE S WITCH PERFORMANCE:	
passband	18 to 26 GHz
insertion loss (on)	> -0.3 dB
insertion loss repeatability	c 0,00015 dB
isolation (off)	< - 45 dB
return loss (both modes)	< - 40 dB
settling time	-5 m s
radiometric self-heating of reference load @ 5 Hz switching	c 0.03 Kelvin

Table 1: Characteristics of the voice coil actuated vane attenuator assembly used for the prototype **AWVR** system.

C. Final Assembly and Initial Tests

With the working Dicke switch, the prototype AWVR of Figure 7 was completed. Three noise diodes were installed in the prototype so that noise diode stability could be monitored on an on-going basis. This feature is also planned for the final AWVR model. The previous noise diode tests had shown how temperamental these calibrators could be, and the third noise diode would provide the added capability of being able to identify any single failure, As the tests progressed, however, all three noise diodes worked very well. So the third noise diode was eventually utilized for special tests which were conducted to answer other questions. Note that in Figure 7 the third noise diode is injected after the Dicke switch. By injecting the one noise diode after the Dicke switch, the switch stability could be closely watched,

Roof-top tests of the prototype AWVR were started at JPL in August of 1996 and continued into November, The tests were conducted along side an existing WVR of a previous generation (a "D-series" radiometer) to provide an initial calibration and a long term means of monitoring system drift, To the limits of precision in the D-series WVR (~0.5K) the AWVR prototype has not shown any significant instability or serious drift. Lacking a suitable standard, however, we are unable to truly demonstrate 10mK instrument stability on one-day time scales, Such a demonstration is not expected until the first AWVR model is built. We can only note that there has not been more than about 0.5K drift in the system during the first 60 days of testing. Also, the Dicke switch, noise diodes, and temperature control have also performed very well and as yet there has been no indications of problems from any of these components.

5. CONCLUSION

Some basic components of microwave radiometers have been examined and refined. A practical temperature control system suitable for ground based systems has been developed, and believed to be a key to the ultimate stability of such instruments. A new level of noise diode stability has also been demonstrated, along with a new design for a Dicke switch. We believe that these components are now working together in the prototype system and that performance goals are being met, At this time, however, we have no verification of system performance other than the internal cross-checking of the noise diodes and the Dicke switch circuits. A more independent demonstration will not be readily made until a second system can be built. With some cautious optimism, however, we believe that our present course will lead us to a system which will meet the goals. The full 3-frequency AWVR system is now being designed and built based on the work we have presented,

Further tests are on-going with the prototype AWVR to examine the stability with which the noise diode can be referenced to the antenna, This will always be an area of concern since instrument stability depends on the antenna and radome prior to the noise injection circuits, The early failure of the magic-T in the noise diode tests also made us keenly aware of standing wave problems, and the coupling between the antenna and the receiver LNA could present similar pitfalls. Indeed, a conclusion to be drawn from the noise diode tests is that noise diode stability is most dramatically degraded by seemingly minor RF transmission line mismatches. Similarly, a perfectly reliable noise diode and directional coupler will not guarantee radiometer stability if, for example, an LNA (or isolator) input impedance changes in the presence of a poorly matched antenna. In such a case the coupling from the antenna can change in ways that are not properly monitored by the noise diode calibrator.

Acknowledgement

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CALIFORNIA INSTITUTE OF TECHNOLOGY **INTEROFFICE MEMORANDUM**
Jet Propulsion Laboratory **November 25,1996**

TO **Alan Tanner (246-101)**

FROM: **Technology Reporting and Communications Office**

SUBJECT **Inactivation for Patent Purposes**
Novel Technology Report No. 20056/9690
TITLE: VOICE COIL ACTUATED MICROWAVE WAVEGUIDE SWITCH

" Following careful review and evaluation, the following authorized representatives of Caltech and NASA have decided not to seek patent protection for this disclosure:

Michael L. Keller, Caltech Director of Patents & Licensing Tel. No. 395-4567
AND
Thomas H, Jones, NASA Patent Counsel Ext: 4-5179 027
John H. Kusmiss, NASA Assistant Patent Counsel Ext: 4-7770

If you have reason to believe that significant information relating to the patent evaluation of this case may not have been considered; or if, at any time, the importance of this disclosure has increased significantly because of changes in concept, new data, new plans for implementation and use for space or commercial purposes; or receipt of inquiries relating to its actual or planned use; or if, for any reason, you consider this decision erroneous and in need of reconsideration, you are requested to notify M. Keller at the Caltech Office of Patents and Licensing, at 395-4567.

Alternatively, if you desire to obtain a patent for this invention yourself, you must request a waiver from both NASA and Caltech releasing their patent rights,

Although this disclosure is being inactivated for patent purposes, it still may become a NASA Tech Brief. This is a decision which NASA will make in due course.

The time, effort, and initiative you have devoted in originating and reporting this item are sincerely appreciated, for they show that you realized the importance of creative effort, and reflect your willing cooperation in fulfilling our contractual obligations in support of NASA's Office of Technology Utilization and the National Space Program.

We hope your creative efforts will continue, and that you will be reporting additional innovations in the near future.

cc: **JPL Technology Utilization Office**

JET PROPULSION LABORATORY - NOVEL TECHNOLOGY REPORT TRANSMITTAL

TO: **Alan Tanner (246-101)**

FROM: Carla Lewis
DATE: November5, 1996

SUBJECT: NPO-20056/9690
VOICE COIL ACTUATED MICROWAVE WAVEGUIDE SWITCH

Following careful review and evaluation, authorized representatives of Caltech have decided not to seek patent protection for this disclosure,

A copy of your above identified Novel Technology Report has been forwarded to the NASA Management Office for patent consideration.

You will be contacted when a final decision has been made.

NOVEL TECHNOLOGY SUBMISSION - STATUS REPORT

October 25, 1996

To: **Alan Tanner (246-101)**

From: **Technology Reporting and Communications** (TRAC)

Subject: **Item No. 9690 Docket No. 20056**
VOICE COIL ACTUATED MICROWAVE WAVEGUIDE SWITCH

The current status, or recent change in status, of the above-identified item of novel technology is given below:

[X] This case **has been docketed for early preparation of a Novel Technology Report. Please refer to the above "Docket" number in all communications with our office regarding this case.**

[1 Requires additional information, but is being logged on our records and is being temporarily put on hold pending further development for the next 6-12 months.

[1 Is being INACTIVATED. No future follow-up is expected.

If you have questions regarding this matter please refer them to the undersigned. **Thank you for your cooperation** in bringing this item to our attention. Your continued cooperation in achieving the reporting, patenting, utilization and transfer of novel technology will be sincerely appreciated.

Technical Staff Member C. Lewis Ext. 3-3421
Carla Lewis